Criteria for high-quality carbon dioxide removal

CARBON DIRECT

Microsoft

Introduction

The science is clear. In concert with rapid efforts to dramatically reduce greenhouse gas (GHG) emissions, the global community must also pursue carbon dioxide removal (CDR) at an unprecedented scale. The Intergovernmental Panel on Climate Change estimates cumulative removal needs of 100–1,000 billion metric tons of carbon dioxide ($GtCO_2$) globally by 2100, with interim annual removal rates that approach 10 $GtCO_2$ by midcentury. This challenge will require CDR methods using both natural and engineered systems.

Both Microsoft and Carbon Direct are committed to development of this critical market.

- Carbon Direct was founded in 2019 with a mission of rapidly scaling carbon dioxide removal. Combining scientific expertise and financial capital to scale carbon dioxide removal and utilization into a global industry, the Carbon Direct team of experts is working to address the unprecedented need for large-scale carbon management.
- In January 2020, Microsoft announced its commitment to become carbon negative by 2030 and articulated the need for large-scale CDR, aiming to remove all historical carbon emissions since its founding by 2050.
- In January 2021, Microsoft announced its first portfolio of 1.3 million metric tons of CDR, after executing its first request for proposals for CDR.

Over the past year, collaborations between Microsoft, Carbon Direct, and the emerging carbon dioxide removal industry have shown a common pattern: reviewing far more projects that did not meet our criteria for high-quality CDR than projects than did. Both organizations recognize that carbon dioxide removal project developers and purchasers lack a common framework for what constitutes a best-in-class project. Microsoft elaborated on this need in a January 2021 white paper, calling out the need for clear accounting of carbon removal and critical guidelines for additionality, durability, and leakage.

To begin to address this critical gap, Carbon Direct's multidisciplinary scientists developed this document to detail both overarching principles and tailored recommendations for a wide range of carbon dioxide removal methods that use natural and/or engineered systems. **The purpose of this document is to support and guide candidate suppliers for Microsoft's July 2021 RFP, and to provide a broadly applicable set of benchmarks to encourage market standardization going forward.** In publishing it, we hope that a wide audience of stakeholders will use it as guidance on what constitutes high-quality carbon removal.

The principles for CDR and the specific guidance by method that follow are intended to help project developers initiate high-quality projects. We emphasize that the following information is not a substitute for pre-purchase due diligence to demonstrate scientific efficacy and validation. This document is not intended to replace existing industry standards, which provide important—though in some cases imperfect or underdeveloped—quality assurance. We encourage existing registries to consider how these criteria could influence their protocols going forward.

The science of carbon dioxide removal is evolving, and this document will progress with it. Carbon Direct will soon also publish guidance on additional best-in-class projects for more nascent forms of CDR to complement those included in this document. Promising methods for carbon dioxide removal not included in this document include blue carbon, macroalgae cultivation, peatland and freshwater wetland restoration, carbon dioxide utilization, and ocean alkalinity enhancement. The absence of guidance in this document on these emerging forms of CDR is not intended to imply a preference for the following methods; however, the methods included in this document reflect most projects that are either operational, planned, or under development.

Looking ahead, stakeholders must have confidence in the quality of CDR solutions as a precondition for rapidly scaling removals to the volume we need globally. We look forward to working with CDR project developers and buyers to refine the following principles as we work together towards achieving high-quality growth in this nascent market.

In this document

Essential principles for high-quality carbon dioxide removal

The following common set of shared principles can help characterize high-quality CDR projects. Note that in each case we outline considerations that "must" or "should" be considered; here we use these terms to differentiate between minimum viable project characteristics (*must*) versus ideal project characteristics (*should*).

Additionality and baselines

Removals are **additional** if they would not have occurred without carbon finance. Developers must measure the removals claimed against a **baseline** which should represent a conservative scenario for what would likely have happened without carbon finance (the "counterfactual").

- **Project developers must:**
  - Demonstrate that they require carbon finance to implement their project.
    - When there are multiple finance streams supporting a project, the project developer must convincingly demonstrate that the removals are a result of carbon finance. Even with substantial non-carbon finance support, projects can be additional if investment is required, risk is present, and/or human capital must be developed.
  - Show that the project is not required by existing laws, regulations, or other binding obligations.
  - Quantify the most plausible baseline for carbon stocks and flows.
    - Baselines must account for both recent and projected changes in carbon stocks and flows.
    - Baselines should be robust, conservative, and site specific.
- **Project developers should** provide full project financials to demonstrate additionality.

Carbon accounting method

Carbon accounting involves the use of repeatable and verifiable methods to ensure that all greenhouse gases associated with a project are accounted for in a transparent manner, including using cradle-to-grave life cycle assessments (LCAs). This should account for any uncertainties in those estimations in a conservative manner to avoid overestimating the climate benefits of a project.

- **Project developers must:**
    - Cite carbon accounting methods employed.
    - Clearly delineate removed, reduced, and avoided emissions on an annual basis, including breakouts by greenhouse gas type.
    - To avoid double counting, ensure the same carbon removals are not claimed by more than one entity.
        - Double counting in the context of countries' Nationally Determined Contributions under the Paris Agreement is currently under debate at the international level, and CDR claims and accounting should align with the outcomes of these discussions.
- **Project developers should:**
    - Use a peer-reviewed and scientifically supported accounting methodology for the given removal method and document those sources as appropriate.
    - Conduct a comprehensive LCA, the result of which must conservatively quantify all GHG emissions associated with the full suite of inputs and products from the operation.
    - Use regionally appropriate sampling and data collection methods to quantify emissions and removals associated with a project instead of solely model-based or statistical methods.

Do no harm and pursue co-benefits

Doing no harm involves the avoidance of negative impacts to economic, social, and environmental systems stemming from a CDR project. Because concerns vary by project type and context, the potential harms that follow are not exhaustive but are rather intended to describe some of the more common potential negative impacts across all project types.

Beyond simply avoiding harm, ideal projects will be ones that pursue co-benefits by advancing sustainable livelihoods and environmental justice, building climate resilience, supporting water conservation, and protecting ecosystems and biodiversity.

- **Project developers must:**
    - Show that projects have a low risk of any materially negative impacts on the surrounding ecosystems (including soil health, biodiversity, water, criteria air pollution) or on local communities.
    - Articulate a strategy for mitigation of impacts to air, water, and land quality.

    - Account for ecosystem effects under changing climatic conditions.
    - Transparently report any use of toxic and/or persistent environmental pollutants, including pesticides.
- **Project developers should:**
    - Advance sustainable livelihoods, build climate resilience, support water conservation, and protect ecosystems and biodiversity.
    - Detail the full life cycle emissions of fossil energy production and consumption and provide a plan to minimize their impacts.
    - Aim to minimize transportation needs for critical operations to limit carbon and criteria pollutant emissions.
    - Plan to adapt feedstocks as industrial processes evolve to reduce carbon footprint and waste production (circular usage).
    - Avoid using pesticides banned in the United States or European Union and avoid using listed persistent organic pollutants.

Durability

Durability is defined as the physical integrity of carbon storage over time. The durability of stored carbon is limited by both natural and social risks of reversal, which can cause carbon to be released prematurely. Until widely accepted methods are developed to equate varied durability terms, longer and more durable storage terms have greater value.

- **Project developers must:**
    - Provide a projected duration (in years) over which removed carbon will be stored.
    - Monitor the stored carbon and demonstrate the ability to reliably detect reversal events.
    - Conservatively estimate a project's risk of reversal using the best available science and accounting for present and future climate change.
    - If not addressed at the protocol level, identify who is liable for remediating the reversal of stored carbon.
- **Project developers should:**
    - Site projects in areas with low risk of reversal and implement ongoing risk mitigation measures to minimize the impact of future reversal events, including future risks associated with climate change.
    - Use insurance-type products, such as a buffer pool, to address the risk of underperformance, which:
        - Conservatively reflect a scientifically substantiated risk of reversal, taking into account possible increases in risks associated with climate change.
        - Dictate that intentional reversals must be remediated on a 1:1 basis, even in excess of any buffer pool by the project owner.
        - Remove a project's buffer pool contributions at the end of the project's life.

Environmental justice

Environmental justice embodies the idea that all individuals should be equitably protected from environmental risk, and equitably empowered to participate in the environmental decision-making processes that could affect them. It begins with acknowledging past and present harms to communities of color, low-income communities, and other communities on the front lines of the climate crisis and racial and economic injustice. It redirects leadership, resources, and decision-making to the hands of these communities who are most affected and previously excluded.

- **Project developers must:**
  - Engage local communities in an ongoing and transparent manner throughout the project lifetime and adopt best practices for engagement.
  - Address worker compensation in their project proposals and commit to compensate workers with living wages.
  - Avoid development or disturbance of land that has been identified as culturally sensitive or ecologically important by community stakeholders.
  - Prevent community displacement.
  - Explicitly detail impacts to water, air, and land, and describe a strategy for mitigating community health impacts.
  - Have public carbon reduction targets and clean energy transition commitments.
- **Project developers should:**
  - Actively promote long-term sustainable livelihoods and economic opportunities for local communities.
  - Clearly articulate whether they will provide benefits to under-resourced and marginalized populations, generate wealth and economic empowerment, and/or foster community involvement with CDR projects.
  - Detail any associated land-use changes, including any new infrastructure required for project deployment, which could have negative community consequences.

Leakage

Leakage involves the risk of displacing activities that cause GHG emissions from the project site to another geographic location (including across international boundaries) through both economic and physical means. Economic leakage occurs when the market demand for an emitting activity is sustained despite the development of a CDR project. Physical leakage (reversals) occurs when carbon that is stored throughout the course of a carbon offset project is re-released into the atmosphere through either voluntary (that is, intentional) or involuntary (for example, extreme weather events) means. Physical leakage is a risk for both engineered and nature-based CDR methods and discussed in the durability principle previously.

- **Project developers must** conclusively demonstrate leakage avoidance, or robustly and conservatively account for the carbon impacts of leakage caused by the project.

- **Project developers should** work to diminish leakage risk in their project design given the difficulties of accurately quantifying leakage.

Monitoring, reporting, and verification (MRV)

Monitoring, reporting, and verification (MRV) involves the development of and adherence to a plan for long-term monitoring of the project for the purposes of quality assurance. This includes adherence to national and subnational regulatory regimes, project development methodologies, and registry protocols where applicable.

- **Project developers should:**
  - Show the modeled performance of proposed projects.
  - Obtain third-party verification of their CDR process and removal volumes.
  - Ideally, directly measure carbon removed throughout the duration of the project rather than rely only on estimates from modeled processes.
  - Adapt MRV practices based on the best available science and industry practices and update as appropriate as methodologies evolve.

Other considerations

Depending on the project type, other considerations may be relevant, including:

- **Feedstock.** Project developers should ensure that a reliable source of sustainable feedstock will be available for the duration of the project, and include all emissions associated with the primary feedstock and any secondary reactants/feedstocks in their overall LCA.
- **Infrastructure.** Project developers should outline all major infrastructure requirements necessary for the project's success, as well as explain how they would interface with existing infrastructure.
- **Product end fate and storage.** Project developers should ensure that any end products from CDR processes will promote product durability, end-use recycling, or long-duration storage (and these products must be included in their LCA).
- **Duration.** Where applicable for CO_2 storage products, project developers should indicate a duration of storage, support this duration with sound and transparent scientific evidence, convey any risk and uncertainty, and outline how, in connection with their MRV plan, they will evaluate and mitigate early reversals.
- **Scalability.** Project developers should describe, if possible, plans or opportunities to scale supply over time and any major impediments to scaling. They should also describe potential adverse environmental impacts from scaling their operations.

Forestation and agroforestry

Forestation, including reforestation and afforestation, is the process of planting trees to establish forests or woodlands. Agroforestry entails the integration of trees into agriculture production systems. Given the large amount of degraded land globally, forestation and agroforestry hold tremendous opportunities to remove carbon from the atmosphere and generate substantial co-benefits for people and nature. Given the complex and place-based social, ecological, and economic dynamics of land use, however, developers should only site projects where socially or environmentally appropriate. Forestation and agroforestry project developers should adhere to the following principles, which are additional to those described previously under Essential principles for high-quality carbon dioxide removal.

Additionality and baselines

- **Project developers must:**
  - Determine the natural regeneration baseline using the best available science to predict natural seedling establishment and forest growth in the absence of tree planting.
- **Project developers should:**
  - Demonstrate that forestation or agroforestry activities are a result of carbon finance or could not occur otherwise (for projects with non-carbon finance streams, such as from expected timber sales or conservation funds).
  - Establish control plots to directly measure natural regeneration over the course of the project.
  - Use remotely-sensed data when claiming a negligible natural regeneration baseline to show that natural recovery of forest is very unlikely to occur.

Carbon accounting method

- **Project developers must:**
  - Use statistically valid sampling methods and best-available models (for example, allometric equations) for quantifying above-ground carbon.

    - Measure and monitor changes in soil carbon when claiming removals in soils, using the criteria for high-quality soil carbon.
- **Project developers should:**
    - Employ validated and regionally calibrated methods and/or use ground inventories to validate remotely sensed measurements of above-ground biomass changes.
    - Use site-specific data and/or collect data needed to parametrize models used to estimate biomass changes (such as species-specific allometries and wood densities measurements).
    - Use data from in-situ sampling or conservative root:shoot ratios (that is, use smaller ratios to mitigate uncertainty) to quantify changes in below-ground carbon.
    - If soil carbon is not directly measured, establish projects on lands where the net impact of forestation or agroforestry on soil carbon is most likely to be net positive.
    - Quantify any GHG fluxes associated with site preparation including removal of existing vegetation (and if GHG fluxes are determined to be de minimis the project developer should articulate why).
    - Include a life cycle assessment of harvested products for agroforestry and plantation projects.
    - Account for applicable indirect climate impacts.
        - For example, projects occurring in high altitude/latitude areas should account for changes in albedo due to establishment of tree cover.

Do no harm and pursue co-benefits

- **Project developers must:**
    - Show that projects have a low risk of any materially negative impacts on the surrounding ecosystems (including soil health, biodiversity, water, criteria air pollution) or local communities.
    - Articulate a strategy for mitigation of impacts to air, water, and land quality.
    - Account for ecosystem effects under changing climatic conditions (e.g., an increase in fire risk).
    - Transparently report any use of toxic and/or persistent environmental pollutants, including pesticides.
- **Project developers should:**
    - Advance sustainable livelihoods, build climate resilience, support water conservation, and protect ecosystems and biodiversity.
    - Detail the full life cycle emissions of fossil energy production and consumption, and provide a plan to minimize their impacts.
    - Aim to minimize transportation needs for critical operations to limit carbon and criteria pollutant emissions.

  - Plan to adapt feedstocks as industrial processes evolve to reduce carbon footprint and waste production (circular usage).
  - Avoid using pesticides banned in the United States and European Union, and avoid using listed persistent organic pollutants.

Durability

- **Project developers must** take active and ongoing measures to mitigate identified risks (for example, forest thinning in fire prone areas).
- **Project developers should:**
  - When initiating projects that involve harvesting, incorporate harvested biomass into long-lived wood products, either traditional (such as lumber, oriented strand board) or emerging (such as biochar, cross-laminated timber).
  - Plant species adapted to future climate conditions and apply planting patterns that foster resistance to disturbance.
  - Use the best available information to forecast future risks of disturbance to planted forests, and situate projects in areas of lower risk.
    - Salient disturbance risks include but are not limited to direct and indirect impacts of climate change, drought, fire, insects, disease, and social disturbances.

Environmental justice

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- **Project developers must:**
  - Engage local communities in an ongoing and transparent manner throughout the project lifetime and adopt best practices for engagement.
  - Address worker compensation in their project proposals and commit to compensate workers with living wages.
  - Avoid development or disturbance of land that has been identified as culturally sensitive or ecologically important by community stakeholders.
  - Prevent community displacement.
  - Explicitly detail impacts to water, air, and land, and describe a strategy for mitigating community health impacts.
  - Have public carbon reduction targets and clean energy transition commitments.

- **Project developers should:**
    - Actively promote long-term sustainable livelihoods and economic opportunities for local communities.
    - Clearly articulate whether they will provide benefits to under-resourced and marginalized populations, generate wealth and economic empowerment, and/or foster community involvement with CDR projects.
    - Detail any associated land-use changes, including any new infrastructure required for project deployment, which could have negative community consequences.

Leakage

- **Project developers must:**
    - Provide robust and conservative estimates of leakage rates and defend the methods used to determine the reported rate.
    - Ensure leakage deductions are taken and properly accounted for.
    - When claiming low leakage rates, provide evidence that project lands are degraded lands, have low economic value, or that project activities do not significantly displace existing land uses. They must demonstrate this by showing that either:
        - There has been minimal past agriculture use over the preceding decade, they are not operating in an area of active land use change, and that the lands are predicted to have low likelihood of future agriculture land use.
        - Tree planting synergizes with ongoing agricultural practices.
- **Project developers should** use remotely-sensed land use data to determine leakage estimates, especially when coupled with models of land-use change.

Other considerations

- **Project developers should:**
    - Develop seedling planting and monitoring plans to maximize the probability of tree survival during the critical three- to five-year establishment phase, including physical infrastructure and human capacity considerations.
    - Use cost-effective forestation techniques such as applied nucleation or assisted natural regeneration.
    - Consider the impacts on biodiversity (both benefits and costs) when selecting species for forestation.

Improved forest management (IFM)

Improved forest management (IFM) involves management changes that increase carbon stocks in forests and in harvested wood products. In practice, realizing and quantifying carbon removal benefits from IFM projects has been difficult. IFM projects have been hampered by uncertainty in project baselines, additionality, and the impacts of market leakage. These uncertainties make accurate quantification of IFM carbon removal challenging, and have tended to result in current IFM protocols overestimating rather than underestimating carbon removals. Until further research resolves these challenges, priority should be given to projects with less uncertainty in these factors and those that use conservative assumptions to quantify removals. IFM project developers should adhere to the following principles, which are additional to those described previously under Essential principles for high-quality carbon dioxide removal.

Additionality and baselines

- **Project developers must** implement conservative baselines that:
    - Reflect initial carbon stocks and carbon stocks over the recent past (at least 10 years, preferably more).
    - Account for recent or projected changes in forest product demand (for example, projects located in regions with decreasing harvesting trends, such as those due to closed mills, can be expected to have increasing baseline stocks).
    - Are appropriate for the specific project site rather than only reflecting regional averages.
- **Project developers should:**
    - For projects with multiple charitable and climate-related revenues, demonstrate that IFM activities above the baseline are unequivocally a result of carbon finance.
    - Move towards adopting baselines which allow for quantitative, probabilistic assessments of additionality.
        - Statistical land use models have long been used in planning and academic research to create probabilistic baselines.

Carbon accounting method

- **Project developers must** use the best available tools to measure and verify changes in carbon storage, including:
    - Statistically representative field inventories and/or remote sensing.
    - Allometry based on published regional- and species-specific data.
    - Reporting carbon pools with increased storage only where data and measurements can be well substantiated (for example, ignoring increases in soil carbon when uncertainty is high).
    - Reporting all carbon pools with decreased storage resulting from project activities.
- When using remotely sensed data, **project developers should** validate any measurement with field inventories.

Do no harm and pursue co-benefits

- **Project developers must:**
    - Show that projects have a low risk of any materially negative impacts on the surrounding ecosystems (including soil health, biodiversity, water, criteria air pollution) or local communities.
    - Articulate a strategy for mitigation of impacts to air, water, and land quality.
    - Account for ecosystem effects under changing climatic conditions.
    - Transparently report any use of toxic and/or persistent environmental pollutants, including pesticides.
- **Project developers should:**
    - Advance sustainable livelihoods, build climate resilience, support water conservation, and protect ecosystems and biodiversity.
    - Detail the full life cycle emissions of fossil energy production and consumption, and provide a plan to minimize their impacts.
    - Aim to minimize transportation needs for critical operations to limit carbon and criteria pollutant emissions.
    - Plan to adapt feedstocks as industrial processes evolve to reduce carbon footprint and waste production (circular usage).
    - Avoid using pesticides banned in the United States or European Union, and avoid using listed persistent organic pollutants.

Durability

- **Project developers should** maximize the durability of carbon storage by:
    - Improving forest health and reducing disturbance hazards (such as wildfire, insects, drought) on project lands, including decreasing the risk of disturbance-induced mortality associated with historical management practices such as fire suppression and adverse species selection.
    - Designing projects that are on lands with a lower natural reversal risk.
    - Incorporating harvested timber or biomass into long-lived wood products, either traditional (such as lumber, oriented strand board) or emerging (such as biochar, cross-laminated timber).

Environmental justice

Environmental justice embodies the idea that all individuals should be equitably protected from environmental risk, and equitably empowered to participate in the environmental decision-making processes that could affect them. It begins with acknowledging past and present harms to communities of color, low-income communities, and other communities on the front lines of the climate crisis and racial and economic injustice. It redirects leadership, resources, and decision-making to the hands of these communities who are most affected and previously excluded.

- **Project developers must:**
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    - Address worker compensation in their project proposals and commit to compensate workers with living wages.
    - Avoid development or disturbance of land that has been identified as culturally sensitive or ecologically important by community stakeholders.
    - Prevent community displacement.
    - Explicitly detail impacts to water, air, and land, and describe a strategy for mitigating community health impacts.
    - Have public carbon reduction targets and clean energy transition commitments.
- **Project developers should:**
    - Actively promote long-term sustainable livelihoods and economic opportunities for local as well as marginalized communities.
    - Clearly articulate whether they will provide benefits to under-resourced and marginalized populations, generate wealth and economic empowerment, and/or foster community involvement with CDR projects.
    - Detail any associated land-use changes, including any new infrastructure required for project deployment, which could have negative community consequences.

Leakage

- **Project developers must:**
    - For projects that reduce timber harvesting, use conservative leakage assumptions and robustly defend these estimates, taking into account domestic and international leakage.
    - Establish contractual agreements that prevent activity leakage.
        - Activity leakage occurs when a landowner shifts the regulated activity outside of the project boundary.
- **Project developers should:**
    - Ensure market leakage is deducted at the same time that increased stocks are credited, even if existing offset protocols do not require this standard.
        - Market leakage occurs when an IFM project which reduces timber harvesting induces landowners outside the project boundary to increase production. Market leakage can be very difficult to predict and measure. This deep uncertainty presents a problem for accurately assessing leakage risks and assigning appropriate carbon deductions.
    - Be aware that leakage risks for projects are likely highest:
        - In regions where mills are running at capacity due to high demand in wood product markets and timber supply is responsive to price changes.
        - In regions where large amounts of non-participating lands can produce similar timber products.
        - Where the wood products that would otherwise be produced on the project lands are highly substitutable.
    - Work to eliminate or minimize leakage risk by initiating projects that do not reduce long-term timber harvest rates. Project activities that typically do not reduce long-term timber harvest rates include:
        - Forest restoration with little decrease in timber harvesting.
        - Reduced impact logging.
        - Increased stand productivity through better stand management (such as thinning).
        - Increased forest fiber utilization.
        - Extended rotation lengths on commercial timberland while employing very conservative leakage rates.

Soil carbon

Since the inception of human agriculture, soils have lost over 500 $GtCO_2e$[1] globally, contributing significantly to climate change and reducing the long-term viability of conventional agricultural management. In response, agricultural producers have begun implementing conservation and/or regenerative practices to restore the carbon previously stored in soils. Soil carbon project developers should adhere to the following principles, which are additional to those described previously under Essential principles for high-quality carbon dioxide removal.

Additionality and baselines

- **Project developers must:**
  - Document baseline emissions from business-as-usual management using control plots or historical soil carbon data.
  - Demonstrate that the practice implemented is not already standard management practice on the farm or ranch.
- **Project developers should:**
  - Utilize regionally specific baselines to understand whether the site is currently a net source or sink of emissions, and to quantify the improvement associated with beneficial carbon management practices.
  - Ensure that practices aimed at increasing soil organic carbon content do not lead to increases in non-CO_2 greenhouse gases.
  - Not use acreage that has previously hosted carbon projects or has already been managed under conservation practices eligible for carbon project development, unless landowners can demonstrate a consistent baseline of conventional management practices over 10+ years prior to implementation of the project.

[1] Note that the term CO_2-equivalent (CO_2e) serves to standardize the global warming potential of all greenhouse gas types under a common metric.

Carbon accounting method

- **Project developers must:**
  - Document sampling stratification by practice, soil type, crop, and other relevant environmental factors.
  - Describe methods used to assess organic matter and carbon stocks.
  - Conduct soil sampling as a means to validate ("ground-truth") biogeochemical process models (and associated tools like COMET) that estimate soil organic carbon levels; soil sampling must be viewed as a necessary complement to modeling.
  - Take soil cores at a minimum of 30 cm depth below the organic layer, even if existing offset protocols do not require this.
- **Project developers should:**
  - Take soil cores as deep as possible, ideally to 1 meter.
  - Measure organic matter using proven methods, such as dry combustion in a carbon and nitrogen (CN) analyzer.
    - Project developers may use novel technological approaches in addition to proven methods for proof of concept; however, they should not use such methods as substitutes for sample collection and analysis.

Do no harm and pursue co-benefits

- **Project developers must:**
  - Show that projects have a low risk of any materially negative impacts on the surrounding ecosystems (including soil health, biodiversity, water, criteria air pollution) or local communities.
  - Articulate a strategy for mitigation of impacts to air, water, and land quality.
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  - Aim to minimize transportation needs for critical operations to limit carbon and criteria pollutant emissions.
  - Plan to adapt feedstocks as industrial processes evolve to reduce carbon footprint and waste production (circular usage).

    - Avoid using pesticides banned in the United States or European Union, and avoid using listed persistent organic pollutants.

Durability

- **Project developers must** provide a durability term supported by a detailed monitoring and verification plan, including documentation of practice continuation following the crediting period and/or additional soil sampling to demonstrate the carbon remains sequestered for the entirety of the contract period.
- **Project developers should** determine the quality of durability on the basis of verification and recourse mechanisms, and all projects should demonstrate especially robust strategies for ensuring carbon remains sequestered (even in instances of ownership changes or extreme weather events).

Environmental justice

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- Detail any associated land-use changes, including any new infrastructure required for project deployment, which could have negative community consequences.

Leakage

- **Project developers must** detail and quantify leakage risks associated with specific project sites and practices in project design documents, including emissions from livestock, and use conservative leakage rates for set-aside type projects on land currently producing agricultural products that are the most susceptible to leakage.

Monitoring, reporting, and verification (MRV)

- **Project developers should:**
  - Use models that have been calibrated and shown to perform well for the particular soil/climate/management combination to estimate interim carbon removal outcomes in order to reduce the cost of on-site soil sampling and laboratory analysis.
  - Use site-specific soil samples as modeling inputs and for model calibration.
  - Use a conservative adjustment on interim carbon removal estimates.
  - For ex post projects, provide full and comprehensive documentation of all soil sample results that have been verified by a designated third party.
  - For ex ante projects, provide the same standard of detailed spatial, temporal, and process specifications for a sampling and measurement regimen as ex post, and commit to share data verified by a third party in future credited years.
  - Specify a monitoring plan to ensure that practices continue for the full duration of the durability period across all of the project area.
  - Propose a specific methodology for long-term measurement, reporting, and verification of soil carbon stocks.
  - Commit to sharing soil data and implementation insights in an open-source platform.
    - To protect the privacy of individual farmers, data may be aggregated and anonymized at the county or regional level by practice and soil type.

Other considerations

Scalability

- **Project developers should be aware that:**
  - While the on-farm implementation of management practices that sequester carbon in soils is well understood, the precise impact on soil carbon stocks is dependent on site-specific considerations such as soil type, crop, and climate.

- While conservation agriculture practices provide a suite of co-benefits and could reduce reliance on synthetic fertilizers in some contexts, the scalability is ultimately dependent on the willingness of producers to persistently and consistently implement these practices in a verifiable manner.

Biomass-based pathways

Biomass-based pathways for carbon dioxide removal (CDR) describe a range of processes that use biomass to remove CO_2 from the atmosphere (via photosynthesis or chemosynthesis) and sequester that embodied carbon underground (for example, in the form of CO_2 or bio-oil) or in other long-lived storage applications, such as biochar or innovative wood products. Some pathways may also generate a co-product such as electricity or hydrogen. These biomass carbon dioxide removal and storage (BiCRS) technologies can result in sizable and highly durable CDR. The feedstocks for biomass-based pathways can either come from growing dedicated biomass or using waste biomass (such as forest or agricultural residues). Biomass CDR project developers should adhere to the following principles, which are additional to those described previously under Essential principles for high-quality carbon dioxide removal.

Additionality and baselines

- **Project developers must:**
    - Identify the current use, if any, or other fate of biomass resources intended for the project.
    - Identify the most likely counterfactual for biomass resources in question over the time period of the project.
    - Explain the economic viability of the project with or without the requested investment and/or carbon removal procurement, and the role of tax or policy incentives (for example, in the United States 45Q, LCFS) in that viability.

Carbon accounting method

- **Project developers should:**
    - Ensure their net negativity claims are based on a cradle-to-grave life cycle assessment (LCA).
    - Include consideration of temporal character of uptake (growth cycle) and emissions.
    - Include biomass, CO_2, and product transportation.
    - For waste feedstocks, provide detailed accounting and justification of counterfactuals.

- Clearly outline allocation methods for co-products and sensitivity analysis (how allocation might change results).

Do no harm and pursue co-benefits

- **Project developers must:**
  - Show that projects have a low risk of any materially negative impacts on the surrounding ecosystems (including soil health, biodiversity, water, criteria air pollution) or local communities.
  - Articulate a strategy for mitigation of impacts to air, water, and land quality.
  - Account for ecosystem effects under changing climatic conditions.
  - Transparently report any use of toxic and/or persistent environmental pollutants, including pesticides.
- **Project developers should:**
  - Advance sustainable livelihoods, build climate resilience, support water conservation, and protect ecosystems and biodiversity.
  - Detail the full life cycle emissions of fossil energy production and consumption, and provide a plan to minimize their impacts.
  - Aim to minimize transportation needs for critical operations to limit carbon and criteria pollutant emissions.
  - Plan to adapt feedstocks as industrial processes evolve to reduce carbon footprint and waste production (circular usage).
  - Avoid using pesticides banned in the United States or European Union, and avoid using listed persistent organic pollutants.

Durability

- **Project developers using geologic CO_2 or bio-oil sequestration must** create storage sites that are as safe and as permanent as possible using established permitting processes (for example, Class Ia, Class II, or Class VI for deep injection wells in the United States) or alternatively meet ISO 265 standard for CO_2 storage.
- **Project developers across all forms of long-lived storage should:**
  - Quantify and report durability over 10, 100, and, ideally, 1,000-year timeframes.
  - Conduct durability assessments that rely on measurements, not models, whenever possible.
  - Reach relevant agreements (such as technology, operations and maintenance, feedstock, offtake) necessary to attract project finance to mitigate potential reversals due to business continuity and project finance.

Environmental justice

Environmental justice embodies the idea that all individuals should be equitably protected from environmental risk, and equitably empowered to participate in the environmental decision-making processes that could affect them. It begins with acknowledging past and present harms to communities of color, low-income communities, and other communities on the front lines of the climate crisis and racial and economic injustice. It redirects leadership, resources, and decision-making to the hands of these communities who are most affected and previously excluded.

- **Project developers must:**
    - Engage local communities in an ongoing and transparent manner throughout the project lifetime and adopt best practices for engagement.
    - Address worker compensation in their project proposals and commit to compensate workers with living wages.
    - Avoid development or disturbance of land that has been identified as culturally sensitive or ecologically important by community stakeholders.
    - Prevent community displacement.
    - Explicitly detail impacts to water, air, and land, and describe a strategy for mitigating community health impacts.
    - Have public carbon reduction targets and clean energy transition commitments.
- **Project developers should:**
    - Actively promote long-term sustainable livelihoods and economic opportunities for local communities.
    - Clearly articulate whether they will provide benefits to under-resourced and marginalized populations, generate wealth and economic empowerment, and/or foster community involvement with CDR projects.
    - Detail any associated land-use changes, including any new infrastructure required for project deployment, which could have negative community consequences.

Other considerations

Feedstock

- **Project developers must** ensure reliable availability of sustainable feedstock.
- **Project developers should:**
    - Minimize transport of biomass products or CO_2 via diesel truck.
    - Prioritize use of wastes and residues from forests and agriculture as feedstock.
    - When the feedstock is classed as waste, provide evidence that there is no other use for the waste before converting to bioenergy (for example, demonstrate that feedstock will be landfilled or left to decompose if not used in this process).

    - Use feedstocks that consist of lignocellulosic biomass, are not food-based, and have the temporal dimension of regrowth considered in the LCA.
    - Follow the Roundtable for Sustainable Biofuels Standard, or another feedstock certification process of similar rigor.

Product end fate and storage

- **Biochar project developers should:**
    - Verify that biochar is not used for combustion applications or other applications that would lead to rapid return of carbon to the environment.
    - Provide biochar elemental analysis to substantiate storage durability.
    - Ensure safe and appropriate application of biochar to avoid any human health hazards.
        - Developers should limit biochar-application rates to 20 metric tons/hectare to minimize health concerns.
- **Project developers that produce wood products should promote:**
    - Longevity of product in built environment through repair and reuse.
    - Displacement of fossil-intensive alternative.
    - Disposal in well-regulated landfills to maximize carbon storage at end-of-life.

Scalability

- **Project developers should:**
    - Propose projects that have a minimum Technology Readiness Level (TRL) of 7 (≥7), corresponding to a "system prototype demonstrated in a plant environment," as defined by the National Academies, 2019. Specifically, technology should have:
        - Demonstration of an actual system prototype in a relevant environment.
        - Final design virtually complete.
        - Demonstration-scale prototype, defined as 5–25 percent of final scale or design, or a 50-250 t/d dry biomass plant.
        - Undergone large pilot-scale testing using dry biomass feedstock at a scale equivalent to approximately 50-250 t/d.
    - Have experience with execution and management of projects with similar size and scope to the proposed project.
    - Describe key business model risks, including the structure and stability of subsidies, and technical risks, including a reasonable plan to mitigate those risks.

Carbon mineralization

Most carbon on Earth is naturally bound in minerals where it is thermodynamically stable over geologic timescales. It represents the most durable carbon reservoir on Earth. Carbon mineralization projects mimic the natural processes that bind carbon in rock in both underground (in-situ) and above ground (ex-situ) sites. The latter can include alkaline industrial waste streams or mineral soil amendments in forests and agriculture. Carbon mineralization may also include CO_2 utilization in the built environment. Very few mineralization projects have been commercialized despite their durability and capacity, making development of new projects a priority. Carbon mineralization project developers should adhere to the following principles, which are additional to those described previously under Essential principles for high-quality carbon dioxide removal.

Additionality and baselines

- **Project developers must:**
  - Provide baseline studies to quantify additionality that include carbon in solid, liquid, and gas form, metals that contribute to mineral carbonate formation, and alkalinity imported into or exported from the project boundaries.
  - Quantify naturally-occurring rates of weathering and mineralization.
  - Be aware that some feedstocks will have carbonate mineral content that must be quantified in order to properly account for a baseline.
    - Low-risk projects will have low-to-zero baseline carbonate mineral content relative to the amount of mineralized material added by the process.

Carbon accounting method

- **Project developers must:**
  - Use best available measurement methods with built-in redundancy to measure carbon contents and fluxes.
  - Compare upfront carbon emissions associated with project development against carbon uptake annually and over project lifetime.

    - Evaluate and monitor, where appropriate, the impact of the project on other GHG pathways (such as methanogenesis, N-cycle).
- **Project developers should:**
    - If multiple carbon reservoirs are involved in the mineralization process, ensure that they are clearly identified and, if possible, differentiated through tracer or isotopic studies.
    - For in-situ projects, quantify demonstrable mineralization in subsurface sites.
    - Use cost and life cycle assessments that clearly identify and differentiate continuously produced and stockpiled industrial feedstocks.

Do no harm and pursue co-benefits

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    - Show that projects have a low risk of any materially negative impacts on the surrounding ecosystems (including soil health, biodiversity, water, criteria air pollution) or local communities.
    - Articulate a strategy for mitigation of impacts to air, water, and land quality.
    - Account for ecosystem effects under changing climatic conditions.
    - Transparently report any use of toxic and/or persistent environmental pollutants, including pesticides.
- **Project developers should:**
    - Advance sustainable livelihoods, build climate resilience, support water conservation, and protect ecosystems and biodiversity.
    - Detail the full life cycle emissions of fossil energy production and consumption, and provide a plan to minimize their impacts.
    - Aim to minimize transportation needs for critical operations to limit carbon and criteria pollutant emissions.
    - Plan to adapt feedstocks as industrial processes evolve to reduce carbon footprint and waste production (circular usage).

Durability

- **Project developers should:**
    - List carbon release risk scenarios for solid- and liquid-bound carbon, and these risks should be reflected in MRV plans.
    - Present release scenarios that reflect anticipated impacts of climate change and changes in land use or water reservoir development when relevant.

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- **Project developers must:**
  - Engage local communities in an ongoing and transparent manner throughout the project lifetime and adopt best practices for engagement.
  - Address worker compensation in their project proposals and commit to compensate workers with living wages.
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  - Detail any associated land-use changes, including any new infrastructure required for project deployment, which could have negative community consequences.

Leakage

- **Project developers should:**
  - Identify alternative uses of waste and demonstrate best use in terms of greenhouse gas impact (this is critical for projects that utilize industrial waste streams).
  - Evaluate and quantify the impact of the project on land use, especially when project infrastructure encroaches on undisturbed land or high-value land use (such as agriculture).

Monitoring, reporting, and verification (MRV)

- **Project developers must:**
  - Supplement modeling with direct measurement of mineralization rates and amounts.
  - Include quantification of carbonate mineral content in feedstock baseline data.
- **Project developers should:**
  - Include cross verification with redundancy (for example, cross referencing gas / liquid / solid phase fluxes and mass balances).
  - Clearly identify the source of metals (such as calcium, magnesium) contributing to mineral formation, and include in MRV the carbon impact of the metal source.
  - Provide full and comprehensive documentation of MRV protocols and data.
  - Recognize that some feedstocks will have carbonate mineral content and may be heterogeneous, compromising some monitoring methods.
    - Cycling of these materials (dissolution and reprecipitation) can confound other verification tools (for example, radiocarbon).

Other considerations

Infrastructure

- **Project developers should** be aware that additional requirements to baseline infrastructure will depend on how projects interface with existing operations for in-situ (such as geothermal) and ex-situ (such as mining, steel) mineralization.
  - Some ex-situ projects may be greenfield developments, requiring new roads, ports, or facilities.
  - Some in-situ projects may require substantial infrastructure to capture or compress air or CO_2.

Scalability

- **Project developers should:**
  - Consider the size and distance to market or area of application for projects in the built-environment or that involve soil amendment applications.
  - Account for changes to rates of mineralization reactions over time due to consumption of highly reactive material and passivation of feedstock.
  - Be aware that ex-situ mineralization will be limited in scale by feedstock supply and in-situ mineralization by the injectivity and capacity of the subsurface reservoir.

Direct air capture

Direct air capture (DAC) uses machines that separate and concentrate CO_2 directly from the atmosphere for the purpose of long-term storage or for use as a feedstock for carbon utilization. DAC machines generally do not require rare or critical materials, and could be sited in many geographies (including near CO_2 storage resources and stranded energy assets). These attributes suggest that DAC could achieve gigaton-scale removal and as such represents both an important pathway to carbon dioxide removal and a potential backstop technology for climate mitigation. However, an important constraint on DAC is its reliance on large amounts of low-carbon energy, both heat and electricity, which may limit deployment speed and scale. DAC project developers should adhere to the following principles, which are additional to those detailed previously under Essential principles for high-quality carbon dioxide removal.

Additionality and baselines

- **Project developers must:**
  - Clearly demonstrate that increased air capture tonnage would not happen in the absence of the project or carbon income.
  - Include quantification of baseline GHG fluxes and any GHG fluxes associated with site preparation, especially in the context of DAC projects that use geological storage.
  - For DAC projects involving advanced weathering, conduct studies that determine baseline natural weathering and mineralization processes and rates.
- **Project developers should** account for any indirect climate impacts, for example, carbon leakage from neighboring wells as a consequence of injecting carbon at the storage site for geologically stored DAC.

Carbon accounting method

- **Project developers must:**
  - Demonstrate life cycle attributes through reporting.
  - Account for increased emissions due to land-use change from project siting or associated energy demands when performing LCA.

    - For a project using fossil-fuel energy sources, include full life cycle impacts in their carbon accounting considerations (regardless of whether co-capture is involved in the process).
- **Project developers should:**
    - Have a project life cycle of less than 1.3 metric tons CO_2 captured per 1 metric ton removed.
    - Use energy sources with low associated emissions.
    - Ensure measurements include emissions throughout the entire value chain of a project (from upstream to operational emissions) across all types of greenhouse gases.

Do no harm and pursue co-benefits

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    - Aim to minimize transportation needs for critical operations to limit carbon and criteria pollutant emissions.
    - Plan to adapt feedstocks as industrial processes evolve to reduce carbon footprint and waste production (circular usage).
    - Advance sustainable livelihoods, build climate resilience, support water conservation, and protect ecosystems and biodiversity.

Durability

- **Project developers must demonstrate:**
    - Sufficient CO_2 storage capacity at site for full project lifetime.
    - Sufficient injectivity at site, including well count.
    - Low risk for CO_2 release.

Environmental justice

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Monitoring, reporting, and verification (MRV)

- **Project developers must** present a valid and viable MRV plan that adheres to key regulatory requirements (for example, Class VI well permits) for either subsurface storage or carbon utilization products.

Other considerations

Feedstock

- **Project developers must** demonstrate that process inputs have low operational safety risk.

- **Project developers should:**
    - Use earth-abundant inputs, such as magnesium, calcium, silicates, sodium hydroxide, or other such inputs appropriate for a given process.
    - For solvent-based systems, demonstrate ability to produce, transport, store, and manage solvent and solvent degradation products with low risk to operators and neighboring communities.
    - For sorbent-based systems, demonstrate ability to synthesize sorbent at 1 metric ton per year scale or at a scale consistent with the project timeline.

Infrastructure

- **Project developers must** provide a description of low-carbon energy supply, including land/sea requirements for generation technology, capacity factor, and reliability.
- **Project developers should** describe relevant transmission infrastructure, including new electric power lines and CO_2 pipelines.

Product end fate and storage

- **Project developers must** demonstrate displacement of high carbon-intensity products or processes for projects involving CO_2 reduction in combination with DAC-utilization projects.

Scalability

- **Project developers must:**
    - Present valid cost estimates, ideally verified by third parties, peer review, or demonstrated in prior projects.
    - Test thermal and electrical energy supplies to match theoretical energy requirements.
    - Demonstrate the ability to manufacture or procure proposed design components and systems.
    - Ensure a viable low-carbon energy supply at large scale; ideally projects would have contracted or captive energy supplies.
- **Project developers should:**
    - Have demonstrated prototypes as close as possible to at-scale usage.
    - Ensure that technology vendors provide performance and cost data of the whole system and key components.

Conclusion

Thank you for your interest in partnering with Microsoft on carbon dioxide removal. We welcome feedback on the preceding guidance as this new carbon removal market develops. Please email Microsoft's Carbon Removal team at mscdr@microsoft.com with comments and/or questions.